Lab 5. Reflection and Transmission

Name: _____

Section: _____

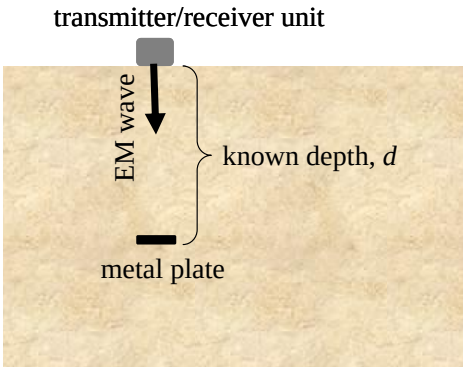
Task 9. The Thracian Tomb: Preliminary Measurements

After the discovery of a large number of Thracian tombs in the "Valley of Roses" in central Bulgaria, the archeologists started calling this area the "Valley of the Thracian Kings". Many of the tombs are situated near Seuthopolis, the capital of the Odrysian kingdom since 320 BC. The cemetery of Seuthopolis included a number of tholos tombs, in which the upper-class were interred, sometimes along with their horses*. These vaulted "beehive" tombs comprise a narrow corridor and a round burial chamber covered by tumuli.

A plenty of small artificial hills are spread all over the valley and it is believed that most of them hide Thracian tombs. Treasure hunters are constantly undertaking small scale excavation works plundering the mounds. However, the Bulgarian Ministry of Culture cannot afford ubiquitous excavation works to prevent the plundering. They need to know with certainty whether a hill is a tumulus or not, to save time and money and forestall the treasure hunters.

You have been invited by the Bulgarian Ministry of Culture to help them in determining the archeological value of the hills. You've accepted. Your idea is to use a small EM wave generator and a receiver (a hand-made GPR) to probe the subterranean recesses. The EM generator emits a very narrow beam, with a cross-section smaller than the receiving aperture of the receiver.

Before you start the real work, you need to undertake some preliminary measurements that will allow you to determine the soil parameters. You know that the conductivity, σ, and the permittivity, ε, strongly depend on the composition of the soil and the recent weather conditions, so you cannot use averaged values reported in books and technical papers.



You decide to dig a pit and bury a metal plate at certain depth, d, and then place the transmitting/receiving unit directly above the plate on the earth surface, shown in the figure to the right. By measuring the received signal, E_R, and the time, τ, it needs to reach the receiver, you hope to be able to deduce the soil parameters, eventually.

The EM wave emitted by the transmitter travels to the metal plate and gets totally reflected by it (reflection coefficient = – 1). It reaches the receiver after traveling a distance of $2d$ in the soil. Soil is a dissipative medium, therefore the wave reaches the receiver attenuated:

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* In book 5, Herodotus describes the customs of various Thracian tribes.

> *The Thracians who live above the Crestonaeans observe the following customs. Each man among them has several wives; and no sooner does a man die than a sharp contest ensues among the wives upon the question which of them all the husband loved most tenderly; the friends of each eagerly plead on her behalf, and she to whom the honor is adjudged, after receiving the praises both of men and women, is slain over the grave by the hand of her next of kin, and then buried with her husband. The others are sorely grieved, for nothing is considered such a disgrace.*
> *Their wealthy ones are buried in the following fashion. The body is laid out for three days; and during this time they kill victims of all kinds, and feast upon them, after first bewailing the departed. Then they either burn the body or else bury it in the ground. Lastly, they raise a mound over the grave, and hold games of all sorts, wherein the single combat is awarded the highest prize. Such is the mode of burial among the Thracians.*

$$E_R = E_T e^{-\alpha 2d}$$

The apparatus you are using generates a 300 MHz, 200 mV/m wave. The receiver sensitivity is 20 mV/m, i.e., the signal must be at least 20 mV/m at the receiver to be detected.

By performing these preliminary measurements, you collect data that allows you to determine the soil parameters, σ and ε.

To complete the assignment:

1. Imagine you have buried the metal plate at certain depth, *d*. Measure the received signal, E_R, and the time, τ, it needs to reach the receiver. The user defined MATLAB function *calread* will provide the measurement data. Before using the function, make sure the file *calread.m* is in your current working directory.
2. Answer the first 4 questions in the Task Report Questionnaire.
3. To answer question 5,
   (i) Take the ratio of equations (7.66) from the book to obtain an expression relating the loss tangent to α and β.
   (ii) Use the provided MATLAB code template to derive the loss tangent in terms of α and β and to get a numerical value.

Suggested MATLAB code template:

```
% Task #9: The Thracian Tomb: Preliminary Measurements
% Use a to denote the attenuation constant, b to denote the phase constant,
and x to denote the loss tangent.
clear all; clc;

% Getting a symbolic expression about the loss tangent:
syms a b x % Constructs symbolic variables a, b, and x.
f=          ; % Equation about x, where x denotes the loss tangent.
x=solve(f,x)% Finds the variable x in terms of the other variables (a and b)
for which f is zero.

% Getting a numerical value for the loss tangent:
a=   ; % Numerical value of the attenuation constant.
b=   ; % Numerical value of the phase constant.
subs(x) % Returns the variable x.
```

4. **BEFORE** continuing, ask your TA to verify your answer to question 5.
5. Answer the rest of the questions in the Task Report Questionnaire.
6. Hand this booklet in by next lab.
7. **Show all your work, to receive full credit.**

Task 9. The Thracian Tomb: Preliminary Measurements

Questionnaire

Give brief but accurate and thorough explanation if necessary. Provide math expressions where needed to show how you've obtained the particular result.

1. What is the depth at which you buried the metal plate? What are the values of the received signal strength and the signal delay?

2. What is the attenuation constant for the wave in the soil? Provide the math expression and the value.

3. What is the speed of the wave in the soil? Provide the math expression and the value.

4. What is the phase constant of the wave in the soil? Provide the math expression and the value.

5. What is the loss tangent of the soil at the frequency used in the measurements? Provide the math expression obtained with MATLAB and the value.

6. What type of medium is the soil at the measurements site at 300 MHz, lossy or lossless, and why? In case it is lossy, specify whether the soil is a low-loss dielectric, a good conductor, or neither.

7. What is the relative permittivity of the soil? Provide the math expression and the value.

8. What is the conductivity of the soil? Provide the math expression and the value.

9. What is the maximum depth, at which the metal plate can be placed provided that such a deep pit could be dug?

Task 10. The Thracian Tomb: Treasure Hunt

So, you have accepted the Bulgarian Government's invitation to help them in determining the archeological value of the hills in the "Valley of Roses". You use a small EM wave generator as a **ground penetrating radar**. The EM wave emitted by the transmitter is scattered due to the heterogeneous conditions in the earth. The back-scattered wave is registered by the receiver. In case there is an air-filled chamber under the earth surface, the EM wave gets reflected by the earth/air boundary upon reaching the chamber and the receiver detects a strong reflected signal (Fig. 1).

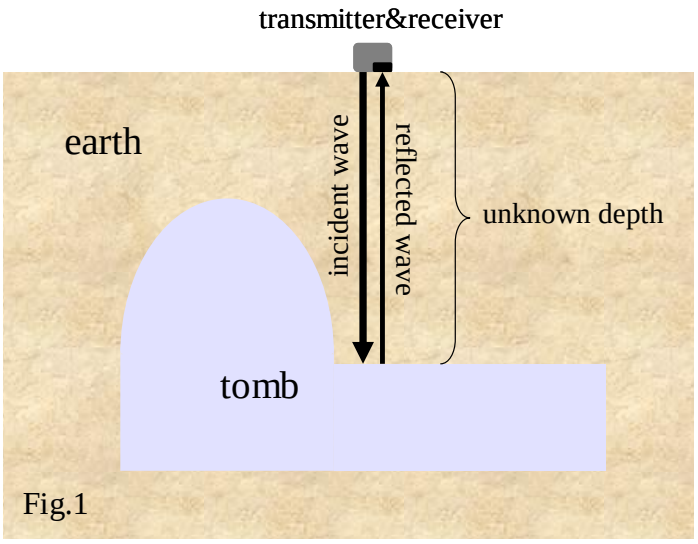

Fig.1

Also, from the magnitude of the reflected signal you are able to determine the thickness of the earth layer covering the tomb.

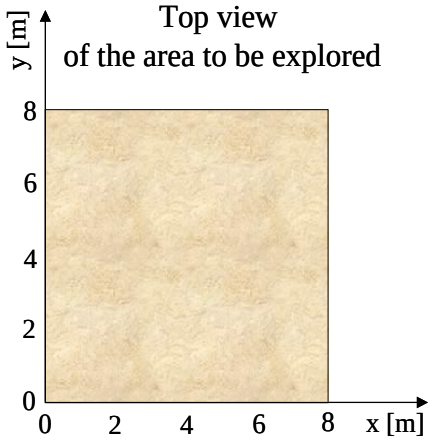

Fig.2

There are a total of six hills in the first series of archeological sites you are to explore. Each of the hills has a large flat top, as shown in Figure 2. The area to be investigated is essentially a flat square of size 8 m x 8 m on the crest of the hill. You determine the measurement positions to be the nodes of a square mesh with a 25-cm step.

The readings you get with the EM wave generator, i.e., the magnitude of the electric field amplitude, are in dB and are being automatically stored in an Excel file named *Data_Thracian_Tomb.xls*. The data about all six hills are being stored in six Excel sheets within the same file, named *Hill_1*, *Hill_2*, *Hill_3*, *Hill_4*, *Hill_5*, and *Hill_6*.

It takes four days to complete the measurements of your first hill. At the end, you use MATLAB to process the data and to visualize the result. The data processing takes a few minutes only, so that by 5 pm on the fourth day you deliver your first report to the Bulgarian Ministry of Culture. Next day, early in the morning, you will start measurements on the next hill. Five more hills are awaiting…

To complete the assignment:

1. Answer the first 7 questions in the Task Report Questionnaire.
2. Use the provided MATLAB code template to compute the depth of the archeological object, if any, from the measurements data, and create a 3D mesh plot of the depth, *d*, versus the two spatial coordinates, *x* and *y*, to map the object. ***Note:*** Use your answer to question 7 in your MATLAB code to convert the experimental data into depth.
3. Run the code six times to process the six sets of data (corresponding to the six hills you've explored) stored in the Excel file *Data_Tracian_Tomb*. ***Note:*** You need to have this file in your current directory to be able to access it.
4. Print out your MATLAB code and the figures.
5. Answer the last two questions of the Task Report Questionnaire.
6. Staple your MATLAB code and the figures to this booklet and hand the paper next lab.
7. **Show all your work, to receive full credit.**

Suggested MATLAB code template:

```
% Task #10: The Thracian Tomb: Treasure Hunt
clear all; clc; figure;

            % Enter the quantities needed for computing the depth

x=0:0.25:8; % Measurement positions along x
y=0:0.25:8; % Measurement positions along y
S=xlsread('Data_Thracian_Tomb','Hill_1'); % Measurement data. Change the hill
number to explore another hill
d=          ; % Compute the depth, d, from the measurement data
mesh(x,y,-d) % Plots a 3D mesh surface of the archeological object
xlabel('x in meters')
ylabel('y in meters')
zlabel('depth in meters')
```

Task 10. The Thracian Tomb: Treasure Hunt

Questionnaire

Give brief but accurate and thorough explanation if necessary. Provide math expressions where needed to show how you've obtained the particular result.

1. What is the penetration depth of the wave in the soil? Provide the math expression and the value.

2. What is the intrinsic impedance of air? What is the intrinsic impedance of the soil at the measurements site?

3. Write the expression about the EM-wave amplitude that reaches the surface of the archeological object in terms of the object depth.

4. Write the expression about the EM-wave amplitude that is reflected from the surface of the archeological object (at the surface of the object) in terms of the object depth.

5. Write the expression about the EM-wave amplitude that reaches the receiver in terms of the object depth.

6. Don't forget that the received signal is in dB. Denote the received signal with *S* and give *S* as a function of the object depth.

7. Solve the equation from the previous question with respect to the depth (distance from the earth surface).

8. Which of the hills hide large archeological objects in their recesses?

9. What is the maximum depth at which an air cavity can be detected using your EM-wave generator? Provide the math expression and the value. Compare this value with the value from question 9, Task 9, and comment.